Head and leg adjustments help insects and legged robots traverse cluttered, large obstacles

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I. Introduction

Despite their superior ability to move in rough terrain compared to wheeled platforms, legged robots are still challenged by cluttered terrain with large obstacles such as earthquake rubble. By contrast, insects like cockroaches are exceptionally good at traversing cluttered terrain [1]. In a recent study of cockroaches traversing grass-like beam obstacles [2], we discovered that kinetic energy fluctuation helps the discoid cockroach transition from pushing across the beams (defined as "pitch mode" due to substantial body pitching) to rolling into and maneuvering through the gaps between beams (defined as "roll mode") that is easier. Further, a potential energy landscape model showed that the transition emerges when the system crosses a barrier to hop from a "pitch" local minimum basin to a "roll" basin. Here, to further understand whether and how the animal uses sensory feedback control to facilitate pitch-to-roll transition and traversal, we studied how the animal adjusts the motion of the head and legs during traversing beam obstacles. We also created a robot as a robophysical model to test how to achieve this pitch-to-roll transition using the combinations of different adjustments.

II. Methods & Results

We challenged the discoid cockroach to traverse a layer of grass-like beams (N = 8 animals, n = 64 trials) and recorded the locomotion using eight high speed cameras. Using markers attached to the animal's head, body, and legs, we reconstructed 3-D kinematics of the animal locomotion in high accuracy.

We divided the traversal process into 3 phases:

(1) Approaching. Initially, the animal used an alternating tripod running gait until colliding with the beams.
(2) Pushing. Then, the animal pushed its body against the beams and pitched up, often laterally exploring the layer of beams using its head and antenna.
(3) Roll traversal. Eventually, the animal rolled its body into the gap between the beams and escaped through.

We discovered that the animal made several adjustments during this transition. First, it continually flexed its head (Fig. 1A) during pushing and roll traversal. Second, it sprawled the hind legs outward during pushing but tucked them inward during roll traversal. Third, it extended one hind leg and flexed the other (Fig. 1B) and flexed its abdomen (Fig. 1C) while rolling into the gap. We hypothesize that by tucking the legs inward, the cockroach could reduce roll stability, and by extending and retracting the legs differentially, the cockroach could generate roll torque, both of the two can facilitate rolling.

To understand the function of head flexion, we added the measured head flexion to our potential energy landscape model (the earlier model had a single rigid body representing both the head and trunk) (Fig. 1D). We discovered that head flexion

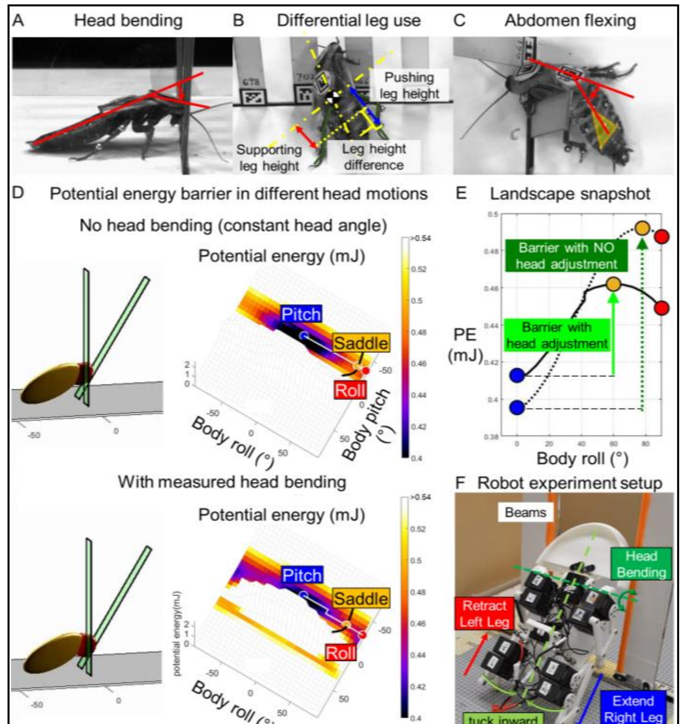

Fig. 1

changed the potential energy landscape and reduced the lowest potential energy barrier to escape from the pitch basin (which occurred at the saddle between the pitch and roll basins) (Fig. 1E). Together, our observations and modeling provided evidence that adjustments of head and leg motion help the animal make the transition and traverse. We developed a legged robot capable of these adjustments, and this increased its performance in traversal using rolling. (Fig. 1F)

III. Discussion

Our research provides insight that besides passive reacting to terrain, the animals also actively adjust their body and appendages to interact with obstacles and traverse. From the robot experiment, we preliminarily show that combinations of the adjustments would help facilitate traversal. For future work, we would add force and torque sensors to the robot's head and legs to further study on the physical meaning of potential energy landscape, and find strategies for using active adjustments according to local force sensing.

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References

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